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**EXTENDING HUMAN EFFECTIVENESS DURING SUSTAINED
OPERATIONS THROUGH SLEEP MANAGEMENT**

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EXTENDING HUMAN EFFECTIVENESS DURING SUSTAINED OPERATIONS
THROUGH SLEEP MANAGEMENT

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Summary

In modern military operations sustained operations (SUSOPs) or sustained performance are often required. The SUSOP is normally much longer than 24 hrs, during which time there usually occurs more than one pulse of intense and continuous work (CW) periods. Three primary factors have limited the duration of CW in the past: (1) Man's limited vision at night, (2) equipment unreliability, and (3) man's limited endurance. With improvements in technology, the duration of CW now appears to be determined primarily by limited human endurance due especially to the need for sleep. The scientific study of the role of sleep, or the importance of work/rest cycles and compliance with sleep disciplines in military exercises so far has not been seriously discussed in logistics.

The purpose of this paper is to show how sleep disciplines or sleep logistics could assist in maintaining, and possibly extending, human effectiveness in periods of CW. Sleep logistics is defined as a factor of military science and operations concerned with planning for the time and place for sleep and includes the cost-benefit analysis of napping (short sleep) over a subsequent period of CW. Naps have, however, a complex nature where they either restore task performance and extend human performance, or paradoxically result in a precipitous drop in performance during post-sleep CW (sleep inertia). The role of sleep logistics is to estimate the restorative power of a short sleep period after CW in sustaining performance in another period of CW. Sleep logistics planning would provide the operational trade-offs of appropriate work-sleep cycles for specific SUSOPs.

The Naval Health Research Center has conducted SUSOP studies with a laboratory simulated U.S. Marine Reconnaissance scenario. Individuals worked physically at 30-40% of their maximal aerobic ability while performing mental tasks during two successive 20-hr CW periods. Each CW period was separated by zero (no sleep) to 8 hrs. of sleep.

Twenty-two Marine Recon volunteers were studied in Phase I of the SUSOP research program. Half of the Marines walked on a motor-driven treadmill 30 mins of each hour during the 20-hr CW periods. Physical exertion was estimated by heart rate to be approximately 30% of their individual maximal aerobic power. (Phases 2-4 measured work output by monitoring VO_2 during physical exercise.) The remainder of subjects remained seated and performed the same visual vigilance task as the walking Marines. After working for 17 out of 20 hrs, the Marines were given a 3-hr nap from 0400 to 0700. The second period of CW (CW2) started one hour after awakening from the nap. In the Phase II study, 18 Marine Corps volunteers followed the same laboratory protocol except that no sleep was given between CW1 and CW2. For Phase III, 8 Marine Corps volunteers experienced the CW scenario as in the previously-mentioned groups, except they did not walk on the treadmill and the CW was only 5 hrs long, giving a full 8-hr sleep between the end of CW1 and the beginning of CW2. The physical work for Phase IV was set at 40% of their individual VO_2 max. They were instructed to maintain this high workload as long as possible without becoming "casualties", i.e. becoming too physically fatigued to complete the scenario. They were given a 4-hr nap from 0330 to 0730 separating the two CW episodes. These experimental designs were necessarily complex, since the objectives were to answer operational questions regarding the combined effects of sleep loss, mood and physical workload upon mental performance. The amount of rest required to restore performance is also a primary objective of these studies.

Results of our studies showed that physical work, in concert with sleep deprivation of CW, did not produce either statistically significant improvements or greater degradation of cognitive and physical task performance in comparison with sleep deprivation alone. The data also showed that second experience of 20-hr long CW did result in significant lowering of physiological and psychological status of individual Marines in coping with the stress and fatigue of CW. This finding suggested that active steps, such as establishing sleep disciplines are mandatory to maintain safe and reliable levels of physical and cognitive performance during repeated CW periods. Nap was found in our series of SUSOP

studies to be one active intervention technique for maintaining and even enhancing performance levels in repeated CW periods. Without sleep between CW1 and CW2, all cognitive performance tests showed significant decrements. However, the duration and timing of naps determined the extent of restoration. Thus, a 3-hr nap taken between 0400 to 0700 was restorative for some task performance, but it had little or no restorative power in some other tasks. In comparison with the 2-hr nap taken between 0400-0600, after a 45-hr CW period in a previous study, the 3-hr nap taken from 0400-0700 after a 20-hr CW period in SUSOP I was more beneficial and restorative. A three-parameter sleep logistics model is suggested for prediction of performance during CW periods. The three parameters are: (1) duration of the CW period, (2) duration of the nap, and (3) time of day when the nap is to be taken. With this model, the need for sleep among military personnel could be balanced against the need for effective manpower to maintain military operations for a successful outcome. The computer model has been developed and applied to derived data. The results showed that a 2-hr nap taken between 0400-0600 after 20 hrs CW is estimated to extend human effectiveness by 4 hrs beyond the normally expected time range, and a 4-hr nap by 12 hrs.

Future studies will vary the time of day of the start of the CW periods and time of naps to determine operational consequences of mission start times and any interaction of time of day of nap and subsequent performance.

"The great number fell victim to the deadly drowsiness that overtakes infantry after calamitous shock losses. They had no interest in what had happened to them; they expressed no curiosity about who had been hit. Lieutenant Robert G. Burns found he could not keep his men awake no matter how he tried. Some were in heavy sleep within two minutes of the bombing. It confused Burns; he could not tell which were the sleepers and which the wounded and dying. He saw men who, having tumbled down the bank, lay still with their bodies half in water. He went to them, thinking they had been hit, then discovered they were sleepers who had rolled down the bank and had not awakened when they slipped into the frigid marsh. Others lay there in their sleep of utter exhaustion. Officers gave over any attempt to rouse these men. Item Company had become a cipher in the column. Burns, a burly, redheaded bruiser who had served as division athletic officer, saw far more than he understood, which but made him wonder more why none of the experts came forward to explain it to him. Burns said "By God, it's funny. Here I had just been worrying about how we could get some sleep." S.L.A. Marshall, Night Drop: The American Airborne Invasion of Normandy; Boston: Little, Brown, 1962, p. 357.

1. INTRODUCTION

The purpose of this paper is to discuss the role of "sleep logistics: or sleep management in Sustained Operation (SUSOP) and to demonstrate how sleep logistics or sleep management can maintain and possibly extend human effectiveness.

2. SLEEP MANAGEMENT (SLEEP LOGISTICS)

Logistics is a branch of military science and operations. It is concerned with planning how to move, feed, clothe and house soldiers, and how to supply them with arms and ammunition (1). Combat effectiveness of personnel is primarily dependent upon adequate logistics. In this paper, we propose that sleep logistics or sleep management, i.e., adequate planning for time and place for sleep, is as important as logistics for food, equipment, transportation, and housing. The purpose of sleep logistics as with other logistics problems is the most effective management of human resources in combat. Sleep logistics may aid SUSOPs by providing necessary "mass, maneuver, and economy of forces" (2).

Although the operational consequences of sleep deprivation on combat effectiveness have been recognized (3), the concept of sleep logistics was first introduced by H.L. Williams in 1964 (4). Sleep logistics has not played, however, any significant role in past or present military planning. Lack of concern with sleep logistics has resulted in a reduction in the number of effective combat personnel available during SUSOPs because of continual fatigue, constant sleepiness, deteriorated mood, lowered motivation, and degraded task performance. Research methods and application of sleep logistics in developing sleep discipline have been already published (5-21).

At NHRC, many field studies have been conducted to determine sleep patterns among naval personnel aboard surface fleet and submarine, and among aviation personnel. Sleep patterns were evaluated for relationships to workload stress, potential health hazards and degradation of task performance. Details of these studies have been published (12-21).

In one of the studies (16), twenty-six naval aviators deployed on the USS Kitty Hawk completed sleep logs during four periods with different workloads. Analysis of these sleep logs suggested that aviators' carrier landing performance (CLP; see (20)) suffered when time between sleep periods fluctuated from very short to very long. Some details on sleep on naval personnel in the surface fleet have been already published (15,17,19,21).

3. SUSTAINED OPERATIONS

3.1 Definition

As mentioned by sociologist Melbin (22), SUSOPs are now accepted as a mode of life in modern society and are not just limited to military professions. Some occupations require a prolonged period of Continuous Work (CW) in performance of essential services. Included are fire fighters, policemen, health care providers, and rail and air transportation, nuclear, petrochemical and steel industry workers. Shift- and night-work systems have historically been utilized to distribute

the burden of continuous services.

Military shiftwork on the battlefield should be researched to develop a work/rest doctrine to meet human resources requirements in SUSOPs (23,24). In many instances, military demands for CW cannot be easily met by orderly sharing of work through arranging soldiers on "shift- or night-work" schedules. In combat, soldiers work for extended periods of time with minimal or no sleep. Battles are fought with no regard to time. Combatants may be allowed to nap, but upon awakening, must rejoin the fighting. This sequence of events where a CW period is followed by a period of short recovery sleep or napping, which is in turn followed by another episode of CW, is often experienced in combat. Vivid illustrations of SUSOPs are given in the World War II experience of the airborne division dropped during the night into Normandy before the Allied assaults on the beaches (3), and in an episode of Marine Reconnaissance operation described by F. J. West, Jr. (25).

Sustained Operations (SUSOPs) of "sustained performance" was defined by Alluisi as "the more or less continuous performance of tasks, sets of tasks or jobs, during four or more hours a day over several weeks, months, or even years" (26, p. 59). J. L. Barber in a conference on continuous operations referred to a statement made by J. Marks that the future battlefield environment would not have the same high level of intensity for an indefinitely long period, but will "still consists of movement to contact, periods of fighting, consolidation, regrouping, resupply." (27, p. 2). Similarly Hegge envisioned that nine to twelve pulses of intensive fighting could be anticipated per day, forcing support elements into a sustained or continuous mode of operations (24).

In this paper, a SUSOP refers to a period involving both preparation for combat and actual combat itself. The SUSOP is normally much longer than 24 hours, during which time there occurs more than one pulse of intense and continuous work, i.e. of fighting, consolidation, triage, and resupply. The duration of such operational cycles of CW could be as long as several days and "influenced by the (fighting) units' capability to fight effectively for longer periods of time, and not by the fluctuating environmental conditions of night and day." (27, p. 2).

The duration of CW was limited in the past because of three factors: (1) man's ineffective vision at night, (2) equipment breakdowns, and (3) man's limited endurance. Night vision equipment is being developed which allows ground forces to function at near daylight efficiency. Technological advances provide states of ruggedness and maintenance ease for major combat vehicles and equipment so that they are operational for long continuous periods of time. With improved night vision and equipment technology, the duration of CW appears determined ultimately by man's limited endurance. Research on SUSOPs will concentrate on finding the means to extend man's capability to continue fighting.

3.2 Human Performance Limit

The single most important limitation in SUSOP appears to be the human factor. This is largely due to the detrimental effects of sleep deprivation and has been well documented in both laboratory and field studies (6,9,23,28-45).

A coordinating draft prepared by the U.S. Army Soldier Support Center entitled, "Soldier Performance in Continuous Operations" (45), lists performance degradations of decreased vigilance, reduced (selective) attention, slowed perception, inability to concentrate, faulty memory, slowed comprehension, slowed response, increased omissions, encoding/decoding difficulties, fuzzy reasoning, communication difficulties, and mood changes.

These performance degradations occur as the duration of SUSOP increases. Haslam and her associates found that observed limit of effective human performance, when working intensively and without sleep, was three days (28). Morgan and his associates (33,34) observed in one experiment that task performance began to drop after 18 hours on the job, and dropped to 67% of baseline towards the end of 48 hrs of CW. These studies, as well as most other studies on the effects of sleep deprivation were measured with tasks which were not truly continuous. The sleep deprived subjects were tested by tasks which might have continued for one hour or more, but were always interrupted by rest pauses. Often one task was discontinued and replaced by another task. The breaks in testing and also of using a different task from one time to

to another gave the subjects a chance to recover from fatigue due to sleep loss. A recent study examined the performances of tracking, pattern memory and addition tasks when they were administered all through a microcomputer without a break for 42 hrs (44). Under this stringent condition, fatigue effects became measurable after only 6 hrs of sustained performance, well before the effects of sleep loss was supposed to have an impact.

In general, the upper limit of human performance for working intensively and continuously, but without the stress of actual combat, are 2 to 3 days when tasks are both physical and mental (6,28,33,34,40,45). Human performance limitation is accentuated by the unavoidable daily circadian performance dip between 0300 and 0600.

4. EXTENDING HUMAN EFFECTIVENESS

4.1 Naps for Extending Human Effectiveness in SUSOPs

Among the few means of extending human effectiveness by lessening sleepiness and an accumulation of fatigue during CW, napping offers the most natural approach. In this paper, the word "nap" is used interchangeably with "short recovery sleep." "Nap" does not refer to the more common usage meaning sleep extra to normal nocturnal sleep. In this sense, naps approximate the more precisely defined Japanese word, "kamin" (nocturnal naps) which was distinguished in Japanese from "hirune" (daytime naps).

4.1.1 Cost/Benefit Analysis of Naps for SUSOPs

If a SUSOP demands human responses around the clock, hence forcing wakefulness for periods longer than 24 hrs, it will eventually result in the total loss of manpower available for the operation, i.e., (1) combat (e.g., offensive, defensive and patrolling operations), (2) combat support (e.g., military intelligence and engineering), and (3) combat service support (e.g., logistic and administrative services).

The sure and best way to maintain human performance effectiveness in a SUSOP is to provide for sleep. Sleep assures that personnel will recover from fatigue. Utilizing current sleep logistic knowledge, a cost/benefit analysis can be made to determine whether loss of man-hours by permitting personnel to sleep can be more than compensated for by the maintenance of the high quality task performance for longer periods. It has been established that the detrimental effects of sleep loss on performance can only be overcome by sleep of sufficient duration, and that 'resting in bed' does not help reduce the need for sleep (51).

Hypothetically, there are two ways to lessen the requirement for sleep. If sleep could be "stored" for use later, then personnel could attempt to sleep longer than normal hours and thereby stockpile "excess sleep" prior to the start of a SUSOP. The feasibility of prophylactic napping in extending human effectiveness was examined by Orne and his associates (46). Another way is to increase the "recuperative" effect of sleep per unit time by the use of drugs and/or naturally occurring sleep inducers. However, to date procedures to enhance restorative power of sleep have not been presented.

Barring future developments of the means to stockpile beneficial effects of naps or the discovery of chemical aids for intensifying sleep, the range of human performance effectiveness can best be extended, at the present time, by providing sufficiently long periods for napping during a SUSOP.

4.1.2 Restorative Power of Naps

A nap is viewed by many researchers as having recuperative power, reducing fatigue and sleepiness (e.g., 29,35-36, 44,46). For habitual nappers, afternoon napping (1500-1700) has been shown to improve performance and mood within a 1.5 to 2-hour period after being awakened from napping (47-50). Habitual naps in the morning (0935-1135) or late at night (2135-2335) were nearly as beneficial as afternoon naps. These studies measured the restorative power of naps taken as extra sleep periods, as identified in Japanese as "hirune". Lubin and others (51), and Hartley (52) reported that naps were beneficial in maintaining task performances and mood in laboratory studies. In a field study, Opstad and his associates noted that naps or micro-sleep, which added up to a total of 3-6 hrs in the middle of 92-120 hrs of a continuous training, significantly reduced the loss in behavioral efficiency of the cadets (35,36). Haslam (28,29) similarly noted

the recuperative power of small amounts of sleep in maintaining job performance. She pointed out that "even small amounts of sleep are beneficial. (29, p. 457).

4.1.3 Side Effects of Naps: Sleep Inertia

Although naps may help in maintaining performance over long periods, performance immediately upon awakening from a nap may show no improvement and, in fact, may even be worse than pre-nap levels. Since Langdon and Hartman (53) reported the precipitous loss of performance efficiency after sudden awakening from nocturnal sleep, sleep inertia has been extensively studied. Sleep inertia has been observed in simple, as well as complex, reaction time tasks (54,55), grip strength (56), short-term memory (57,58), and in complex visual and cognitive tasks (59-61). Sleep inertia is usually short-lasting, and is followed quickly by the recuperative effect of the nap. Sleep inertia has been estimated to last for about 15 minutes after awakening (55), but may disappear as soon as 1 to 5 min after awakening from an afternoon nap (62).

Short recovery sleep, however, taken after a prolonged period of wakefulness has been found to cause more severe and prolonged sleep inertia. In 1972, Morgan and others observed that the worst performance occurred during the first performance occurred during the first performance test session following short 2- or 4-hrs sleep of subjects who had been awake for 40 or 44 hrs. They found, however, that if sleep-deprived subjects were given a 24-hr rest/sleep period, the best performance occurred during the first work period following sleep. They concluded that "if men have endured a stressful period of sleep loss then gone to sleep, one had better not awaken them for duty prior to their having obtained adequate sleep unless one is prepared to expect very low performance efficiency." (63, p. 104-105; see also 65).

A few studies have explored the effects of short recovery sleep after prolonged CW. Naitoh observed that naps might not always be helpful for restoration and maintenance of performance and mood (64). Haslam (29) studied the performance recovery of Logical Reasoning and "decoding" tasks after a 4-hr nap following 90 hrs CW. Post nap testing of a Logical Reasoning task given at 0545 showed that subjects could not do the task within the first five minutes after awakening. This observed poor recovery at the 0545 testing may have resulted from profound sleep inertia reinforced by a circadian decline in performance effectiveness. Wilkinson and Stretton (55), and independently Taub (48), noted that sleep inertia could be detected for as long as 2 hrs post nap. Fort and Mills (66) found performance to be worse upon arousal, particularly when awakening occurred in the first half of the sleep period, indicative of a possible relationship between sleep inertia and Slow Wave Sleep.

4.1.4 Deciphering the Complex Nature of Restorative Power of Naps

Past studies have suggested that less than two hours of recovery sleep, taken between the periods of 2000-0200 (34), 2330-0100 (58), or 0400-0600 (64) has little restorative power on lowered task performance, and sleepiness and fatigue. The fact that the recovery occurred when a two-hour nap was taken from 1200-1400 (64) suggests that a circadian rhythm is involved in a nap's restorative power. Thus, the restorative power of short recovery sleep is complex, and appears to depend on three factors: (1) hours of prior wakefulness, (2) time of day when taken, and (3) duration (69). If recovery sleep is too short and/or it is given at the wrong time of day to those who have been sleep deprived, then naps cause harm to human effectiveness through prolonged sleep inertia. However, by proper management of naps, the time range of high quality performance of personnel engaged in SUSOPs can be extended and lost time and/or reduced effectiveness minimized.

4.2 Applications

4.2.1 NHRC Research on SUSOPs: Rationale and Experimental Design

At NHRC we have been studying the effects of continuous and repeated work episodes on cognitive performance. These studies have examined sleep management as an intervention technique to extend human effectiveness in SUSOPs. We have manipulated the length of and time-of-day for naps (e.g., 64), and determined the restorative power of naps after lengthy

periods of CW. In essence our studies ask: How long can U.S. Marines perform effectively if they work continuously without sleep? Having worked continuously for a long period of time, how much recovery sleep do they need to meet the challenge of an ensuing CW? How may the onset of fatigue be retarded by proper sleep management?

In the SUSOP study we were less interested in the direct effects of CW on performance, mood and sense of fatigue, because these have been described in numerous studies (33,40-43,67-69). Rather, we were interested in the answer to the question of how to optimize performance regarding sleep management in SUSOP: e.g., following CW, how many hours of recovery sleep are necessary to restore a subject to baseline level of performance and mood?

In our study, we have examined U.S. Marine Corps reconnaissance operations (e.g., 25) by simulating some operational components in the laboratory. One crucial operational component is the requirements for moderate to heavy physical work, in addition to the usual requirements for cognitive work. Three levels of a physical workload were selected to control and test for effects on cognitive performance. The overall experimental design of our study is shown in Table 1.

For discussion, we will refer to the experiment involving Groups #1A and #1B as SUSOP I; the experiment involving Groups #2A and #2B as SUSOP II; Group #3 as SUSOP III; and finally, Group #4A1, #4B1, and #4A2, and #4B2 as SUSOP IV.

In our studies, physical workload was adjusted to each individual Marine through reference to his laboratory determined maximal aerobic power at three selected levels: (1) No physical workload; (2) 30% of maximal aerobic power sustained during CW; and (3) 40% of maximal aerobic power at start, but lowered during CW, depending on subject's capability. The workload level of 30% of maximal aerobic power was arbitrarily chosen. However, it is comparable to the physical workload experienced by a platoon of ski commandos in a Franco-Canadian study (30,31). A physical workload of 40% of maximal aerobic power proved to be close to the upper limit of human endurance in our experimental protocol (37,70-72). This physical workload is close to what was experienced in "a combat course" by Norwegian male cadets (73).

We chose to study recuperative power of early morning 3- or 4-hr naps which followed the first 20-hr CW (CW1) and preceded the second 20-hr CW (CW2). As controls, one group did not nap during the period between CW1 and CW2, while another group had 8 hrs of sleep between a shortened CW1 and CW2 (see Table 1).

Table 1. Experimental Design

"Nap" Duration	Physical Workload*		
	0%	: 30% to Start; Sustained	: 40% To Start; Max Effort
8 hours	Group #3	: XX	: XX
4 hours ⁺	Group #4A1	XX	Group #4B1
3 hours ⁺	Group #1A	Group #1B	XX
0 hour	Group #2A Group #4A2	Group #2B	Group #4B2

XX = Data Collection Not Planned. * Physical workload of walking on a motor-driven treadmill for 30 min of every hour for 17 hrs for each CW episode. Physical workload is expressed by % of individual's maximal aerobic power. ** Physical work was near 25%, instead of 30%. + Time of nap was fixed to be during "early morning" hours.

4.2.2 Data Collection Protocol

Figure 1 is the data collection protocol used for all SUSOP studies at NHRC, with the exception that the duration of the CW period was shortened for Group #3 to accommodate 8 hrs of sleep between CW1 and CW2.

These experiments were conducted at the Physical Fitness and Ergonomics Laboratories of NHRC which house a sound-reduced, electronically shielded sleep room and an air-conditioned exercise room. Major equipment used was a DEC MINC 11 computer with two video terminals, and a Quinton clinical research treadmill. An average ambient temperature of 21 C and humidity of 50% were maintained for SUSOP I.

SUSOP I (N = 22; Groups #1A, #1B)

On Monday (Day 1), two Marine Corps volunteer subjects were given graded maximum exercise tests to assess maximal oxygen uptake with simultaneous measurement of heart rate. During the remainder of Monday (Day 1), the Marines were familiarized with the study and trained in the various study tasks. One member of each pair of subjects was randomly assigned

Figure 1. Data collection protocol for SUSOP experiments

	MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
EXPT'L PHASE	Training		Baseline		CW1		CW2		Recovery	
TIME	WA	WB	WA	WB	WA	WB	WA	WB	WA	WB
00 - 01							15A	15B	16A	16B
01 - 02							16A	16B	16A	16B
02 - 03							17A	17B	17A	17B
03 - 04										
04 - 05										
05 - 06										
06 - 07										
07 - 08			----- BREAKFAST* -----							
08 - 09			1A	1B	1A	1B	1A	1B		
09 - 10			2A	2B	2A	2B	2A	2B		
10 - 11			3A	3B	3A	3B	3A	3B		
11 - 12			4A	4B	4A	4B	4A	4B		
12 - 13			5A	5B	5A	5B	5A	5B		
13 - 14			6A	6B	6A	6B	6A	6B		
14 - 15			7A	7B	7A	7B	7A	7B		
15 - 16			8A	8B	8A	8B	8A	8B		
16 - 17			9A	9B	9A	9B	9A	9B		
17 - 18			10A	10B	10A	10B	10A	10B		
18 - 19			11A	11B	11A	11B	11A	11B		
19 - 20			12A	12B	12A	12B	12A	12B		
20 - 21			13A	13B	13A	13B	13A	13B		
21 - 22			14A	14B	14A	14B	14A	14B		
22 - 23			15A	15B	15A	15B	15A	15B		
23 - 24	SLEEP 0		SLEEP 1		16A	16B	16A	16B		

CW = Continuous Work

*Includes time for attachment of ECG electrodes and rifle assembly task.

**Includes time for rifle assembly task.

As the experimental subject and the other as the control. Both Marines performed the same tasks at the same time throughout the experiment, with the only difference in the first half hour of each hourly session (labelled as "A") (see Figure 1), being that the experimental subject was required to perform the alphanumeric visual vigilance task while walking on a treadmill, wearing full combat gear including backpack and rifle. Treadmill speed was determined by heart rate kept as near as possible to the determined rate for 30% of maximal aerobic power. During the 30 min "A" sessions, the control Marine sat in front of a video monitor performing the same alphanumeric visual vigilance task as the experimental subject.

The experiment started at 0800 Tuesday (Day 2). The first work segment, to establish baseline, consisted of 12 one-hr blocks, ending at 2115. The experimental subject then was required to walk on the treadmill for a total of six hours.

The first continuous work period, CW1, began Wednesday (Day 3) at 0800, ending at 0400 Thursday (20-hr CW). After the end of CW1, each subject was allowed a 3-hr nap, from 0400 to 0700 Thursday (Sleep 2 of Figure 1). After being awakened from napping, subjects were given breakfast and then at 0800 the second continuous work episode, CW2, of 20-hr duration began, ending at 0400 Friday (Day 5). After the end of CW2, subjects were allowed to sleep until 1200.

SUSOP II (N = 17; Groups #2A, #2B)

The basic data collection scheme was identical to SUSOP I, except that all subjects remained awake from 0700 Wednesday (Day 3) to 0400 Friday (Day 5), a continuous 45-hr period. As in SUSOP I, each member of a pair of subjects was randomly assigned as either the experimental "exercise" subject or control "no exercise" subject. In SUSOP II, however, spirometer readings of expired air, vice heart rate, of the experimental subjects on the treadmill were monitored to control the physical workload at 30% of maximal aerobic power. The SUSOP II experimental subjects did not walk on the treadmill during Tuesday (Day 2) baseline sessions.

SUSOP III (N = 8; Group #3)

The basic data collection scheme was identical to SUSOP I and II. However, the experimental subjects did not walk on the treadmill, and the duration of CW was shortened to twelve 1-hr sessions in comparison with seventeen 1-hr sessions for SUSOP I and II. This was done to accommodate 8 hrs of sleep between CW1 and CW2.

SUSOP IV (Data now being collected; Groups #4A1, #4A2, #4B1, #4B2)

The basic data collection scheme is identical to SUSOP I and II, except that time for recovery sleep (Sleep 2 of Figure 1) after CW1 starts earlier by 30 min at 0330 and ends later by 30 min at 0730 to accommodate a 4-hr period for sleep.

The Marine subjects are told that the purpose of walking on the treadmill is to determine the maximal physical workload they can endure without becoming "casualties". Initial treadmill speed is increased and an incline is added, increasing the starting physical workload to 40% of maximal aerobic power. Subjects are instructed to try their best to keep up this work level for as long as they can. They are also instructed to request an immediate reduction in treadmill speed and/or incline if they are unable to maintain the pace.

4.2.3 Measures Examined

The details of the performance tasks utilized have been published (74,75; see also 19,64), so they will not be included in details here. As mentioned previously in data collection protocol for SUSOP I, an alphanumeric visual vigilance test was given during a half-hour session labelled "A" (see Figure 1). During the half-hour session labelled "B," tasks of simple reaction time, response alternation performance (a tapping task), logical reasoning, and four-choice serial reaction time were regularly given. Other performance measures included auditory word memory, Educational Testing Service visual memory test, and Miller and Gates Reading tests. The IHRC Mood Scale, School of Aerospace Medicine subjective fatigue checklist, and Kogi subjective fatigue scale were used to measure mood and fatigue.

Heart activity was monitored by electrocardiograph with electrodes placed in the CM5 (manubrium, V5 and RV4) configuration. To measure brain activity during sleep, EEG electrodes were placed on C3 referenced to linked mastoids.

4 was used as an alternate. Right and left EOG recordings were also obtained during sleep. Oral temperature, blood pressure, right and left grip strength were measured on a regular basis. Additionally, two combat-related tasks, rifle disassembly/reassembly and a simulated naval anti-aircraft warfare task, were utilized.

4.2.4 Findings and Discussion

Full descriptions of the specific findings from SUSOP I and II have been published (74,75). One additional paper on the interrelation among physical workload, sleep loss and sleep stages will be published shortly (76). Therefore, in this paper, overall findings will be discussed.

All but two Marine volunteers in the SUSOP experiments were found to be cardiovascularly fit. In SUSOP I, they showed an average maximal oxygen uptake of 53.5 ± 6.2 ml/min/kg of body weight. In SUSOP II, the subjects showed an average maximal oxygen uptake of 50.6 ± 6.4 ml/min/kg of body weight. In SUSOP I, the subjects walked on a zero-grade treadmill surface in full combat gear weighing 25 kg. Treadmill speeds ranged from 3-5 km/hr depending on each subject's cardiovascular fitness. Distance covered in the 23 hrs (6 hrs during the baseline day, and 8.5 hrs for each CW) on the treadmill averaged 93 km. In SUSOP II, average treadmill speed was 3.3 km/hr, and the distance covered in 17 hrs (subjects in SUSOP II did not walk on a treadmill during Tuesday) averaged at 56 km. The physical workload for SUSOP II was about 25% of maximal aerobic power.

Physical Workload Effects

For both SUSOP I and SUSOP II, the physical work in concert with sleep deprivation did not produce either statistically reliable improvement or greater degradation of cognitive and physical task performance in comparison with sleep deprivation alone. In an earlier study at NHRC, exercise was reported to increase performance decrements when combined with sleep loss (51). This latter finding was, however, inconsistent with that previously reported by Webb and Agnes that exercise in concert with sleep loss has no effect on performance (77). Allen and others (32) observed no performance effects in subjects on a treadmill working at 25-30% of maximal oxygen uptake for one hour of every three for a 64-hr period when compared with their performance during which they remained sedentary in another 64-hr episode. In a Franco-Canadian study, Myles and others observed that ski commandos marched at a rate which caused about 30% of maximal oxygen uptake. Myles and others reported that repetitive marching had no effect on grip strength, but decrements were observed on the number of correct response on a Four-Choice serial reaction time task, and also vigilance and mood (30).

Sleep Loss and Nap Effects

Although the effects of physical work were minimal, sleep loss had a great effect upon both the sedentary and exercised subjects. In Table 2 are the comparisons of selected task performance, mood and fatigue scores observed from SUSOP I II and III experiments.

Before sleep loss effects and the recuperative power of naps are discussed, let us note that, despite the complexity of the experimental design, interpretations of the results of our studies are straightforward. As shown in Figure 1, CW1 took place after the Marines had a night of sleep, whereas CW2 took place after they experienced 3 hrs or no sleep. Thus, the difference between CW1 and CW2 in terms of performance, mood and fatigue should reflect the difference in the restorative power of 8 hrs of sleep in contrast to that experienced after 3 hrs or no sleep. Another interpretation of CW1-CW2 differences can be made, however, by recalling the fact that the Marines' motivation to work could have declined during CW2 compared with CW1 due to the monotonous and repetitive nature of testing. If so, performance decrement and changes in mood and fatigue in CW2 were not caused by sleep loss, but by lowered willingness to work hard. The validity of this alternative interpretation can be checked in our study by comparing performance, mood and during CW2 with those during CW1 in SUSOP III. If the Marines in SUSOP III suffered from significant performance decrements and degraded mood and increased sense of fatigue in CW2, these effects resulted from a decline in motivation due to experimental paradigm, because they were allowed a full 8-hr recovery sleep.

Table 2. Summary of Results

Task/Measure	Sleep/hours	Mean CW1	Mean CW2	% Change ⁺	Direction of Change
SRT*(10% slow: msec)	8**	509	524	+ 3.9	Slower RT CW2
	3**	696	916	+31.6	Slower RT CW2
	0**	519	1013	+95.2	Much Slower RT CW2
TRAP*(10% slow: msec)	8	566	513	- 8.5	Faster RT CW2
	3	667	713	+ 6.9	Slower RT CW2
	0	670	794	+18.5	Much Slower CW2
Four Choice (Mean Reaction Time: msec)	8	584	577	- 1.2	No change CW2
	3	687	709	+ 3.2	Slower RT CW2
	0	696	840	+20.7	Much Slower CW2
Logical Reasoning (# Correct)	8	45.8	47.0	+ 2.6	Better CW2
	3	30.5	29.6	- 3.0	Poorer CW2
	0	29.7	24.8	-16.5	Poorer CW2
Alphanumeric Vigilance (% Correct)	8	87.8	89.6	+ 2.1	Better CW2
	3	78.8	67.8	-14.0	Poorer CW2
	0	73.6	55.5	-24.6	Much Poorer CW2
NHRC Positive Mood	8	35.7	33.3	- 6.7	Less Positive CW2
	3	32.7	27.8	-15.0	Less Positive CW2
	0	37.9	29.8	-21.4	Much less Positive CW2
SAM Fatigue Checklist	8	10.8	10.6	- 1.7	Less Fatigue CW2
	3	6.9	9.1	+31.9	More Fatigue CW2
	0	6.8	11.0	+61.8	Much More Fatigue CW2

* "SRT" stands for Simple Reaction Time task, and "TRAP" represents a tapping task.

** "8" = 8-hr sleep permitted between CW1 and CW2; 8 Marines in SUSOP III experiment. "3" = 3-hr sleep permitted between CW1 and CW2; 22 Marines in SUSOP I experiment. "0" = No sleep; 16 Marines in SUSOP II experiment. + = Percent change was calculated by $(CW1 - CW2)/CW1 \times 100$. "Slower RT CW2" means a within-group comparison where slower reaction time was observed in CW2 compared with CW1.

+ Percent change was calculated by $(CW2 - CW1)$

In Table 2 are the means for CW1 and CW2 and the percent change within each group. Performance, mood and fatigue scores in the SUSOP III group showed no change, small nonsignificant degradation, or even improvement during CW2 compared with CW1, although significantly lower "positive" mood was found. This absence of large performance change from CW1 to CW2 suggests that the boredom of being tested repeatedly by the same monotonous tasks did not in itself result in performance decrements. Thus, the significant degradation observed during CW2 in the other SUSOP groups was apparently caused by other factors than lowered motivation.

Performance, mood and fatigue scores of Marines in SUSOP II showed clear decrements, as was expected from past sleep loss research. Performance degradation ranged from 16.5% to 95.2%.

For those involved in sleep management, the behavior of Marines in the SUSOP I experiment should prove most interesting, as it showed the apparent recuperative power of a 3-hr nap taken from 0400 to 0700. The details of this study were published by Englund and others (74) and Naïtch and others (75). In SUSOP I, performance and mood scores were poorer, and fatigue greater in the CW2 phase than in CW1. The observed within-group decrements were significant. Thus, a 3-hr "nap" was not sufficient to allow these subjects to completely recover and prepare for the second CW challenge.

Further statistical analyses of data, shown in Table 2, revealed that the 3-hr nap had as little restorative power as "no sleep" for the same performance measures, i.e., SRT (reaction time of 10% of the response), logical reasoning task (# correct), and alphanumeric visual vigilance task (% correct) (75). Similarly mood and sense of fatigue were not improved significantly by the 3-hr nap over "no sleep" treatment. However, the 3-hr nap had restorative effect equal to the 8-hr sleep for Four Choice serial reaction time (as measured by mean reaction time). We discovered also that the 3-hr nap was beneficial in reducing the rate of performance degradation of the Four Choice serial reaction time task and Simple Reaction Time tasks during CW2 in comparison with those who continued to work without a nap. Thus, the 3-hr nap (0400-0700) was found to be restorative in some task areas and in some aspects of task performance, thus extending human effectiveness. The 3-hr nap (0400-0700) after 20-hr CW was more beneficial and restorative than the 2-hr nap (0400-0600) taken after a 45-hr CW. The 3-hr nap (0400-0700) after 20-hr CW did not result in prolonged sleep inertia.

4.3 Pointers for the Future

In this paper, sleep management is defined and discussed in relation to recent studies to determine whether there may be performance problems in field operations due to varied work/rest schedules. If such problems exist, then sleep logistics analysis can suggest how the problems can be resolved. In field studies cited in this paper, sleep logistics analysis has indicated some poor sleep management practice among naval personnel involved in manning surface fleet as well as among aviation personnel. In the examples of laboratory simulation given in this paper, application of concepts of sleep logistics have revealed problem areas.

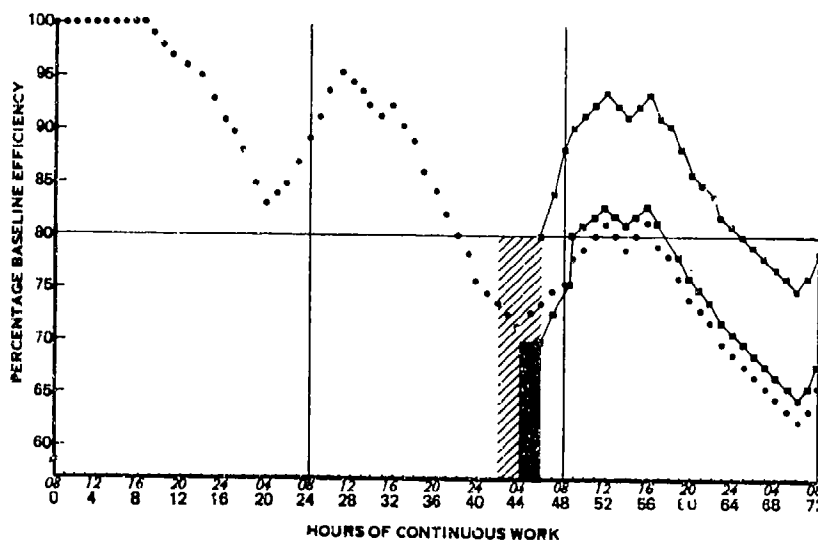
So far, NHRC SUSOP research has focused on finding the optimal duration of recovery sleep and the best time for sleep. Planners for combat scenarios could utilize our findings to maximize performance in available personnel and to extend human effectiveness beyond normally expected range. In actual field exercises, however, a scenario might unexpectedly change and personnel could not comply with the best of pre-planned work/rest schedules. Another contribution of sleep logistics addresses this contingency. Sleep logistics analysis can be employed by the field commander, in response to unexpected changes in the scenario, to predict the consequences to task performance and mood of utilizing available time for sleep.

The first step towards the prediction of behavioral consequences of napping is to model beneficial effects of naps with a simple mathematical equation. In Figure 2 are results of the application of a mathematical model of $Y(t) = X(B,t) + k(w_1 + w_2)$. $Y(t)$ represents performance of a task at time "t", while $X(B,t)$ represents performance of the same task when no recovery sleep was taken by subjects. A "k" is a constant to show the restorative power accrued from napping and its magnitude is proportional to napping duration. Two weighting coefficients, "w1" and "w2" delimit the restorative power, depending on the kind of recovery sleep. The w1 expresses a factor of circadian rhythm in the restorative power of naps, i.e. naps at certain times of day would be more effective for restoring performance and mood. The w2 represents sleep inertia which would subtract from an expected amount of restorative power. In Figure 2, unconnected filled circles show $Y(t)$ value, a typical hypothetical performance curve of a task during a three-day CW without sleep intervention. The Y-axis shows percentage of baseline efficiency. The line with the squares represents the results of applying the above equation to a condition where recovery sleep is permitted from 0400 to 0600 after 20 hrs of CW. The nap period is shown by a black bar. The line with filled squares shows model-predicted performance after 4-hr recovery sleep from 0200 to 0600. The nap period is shown by a bar marked with diagonal lines. This figure should be used as a conceptual aid to grasp the meaning of benefits or performance "enhancement" afforded by napping.

Although the performance curves in Figure 2 are based on derived data, this figure shows utility of sleep management in the field operation. We have specified in the model that an 80% baseline efficiency or better would be required for satisfactory performance. Under this constraint, a total of 3 useful hours would be available for satisfactory performance for the time period from 0600 of the second day to the last hour of 0800 of the third day (see the filled circles

which are not connected). In the case of the 2-hr napping, these "useful" hours extend, i.e., extending human effectiveness by 9 hours. However, even without napping, there are 3 useful hours. Hence, a gain of 6 useful hours (i.e., 9-3) is realized. This 6-hr gain is obtained by expending 2 hours in napping; hence, the net gain is 4 hours (i.e., 6-2). Similar calculations show a net gain of 12 hours for a 4-hour nap. In short, the model shows that a 2-hr nap yields 4 useful work hours, whereas a 4-hr nap yields 12 additional useful working hours when compared with no naps.

Figure 2. Results of applying a model of a nap as an intervention technique to extend useful hours for work.



The model requires knowledge of three parameters: (1) prior hours of continuous work, (2) time of day when sleep was taken, and (3) the duration of sleep taken. With further refinements of the model with use of additional information as to physical fitness of personnel, their physical workload, as well as meteorological and other environmental conditions, the model might be able to indicate how long personnel can continue to work and the performance effectiveness if they are permitted to sleep now for specific level of hours. The sleep logistics model can be easily incorporated to any existing prediction model for human performance in continuous operation (e.g., 78).

Emanski quoted in his briefing (79) what Maj. Gen. J.F.C. Fuller wrote in 1952:

"Once armies went into winter quarters and cut down their operational year by six months. Still armies go into night quarters and cut down their operational day by twelve hours. When are soldiers going to tumble to it that an army which can fight round the clock has a hundred percent advantage over one which can fight only half way around it?"

Sleep management for SUSOPs may provide an answer to General Fuller's question.

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<p>→ Sustained Operations (SUSOPs) represent a prolonged period of continuous work (CW) in the performance of essential services. In many military operations, demands for CW cannot be easily met by orderly sharing of work through arranging soldiers on "shift or night work" schedules. Especially during times of emergency, military personnel must often work continuously without sleep for long hours at physically demanding tasks while remaining mentally alert. This technical paper summarizes four SUSOP studies, I through IV,</p>		

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20. Abstract (continued)

conducted at the Naval Health Research Center, to describe cognitive performance decrements due to continuously working for two episodes of 20 hours each, with a short sleep period of 3 or 4 hours permitted between these two CWs. This paper also reports on an application of "sleep logistics" in evaluation of effectiveness of napping in the early morning period so as to counteract performance decrement due to a CW. Short napping of 3 or 4 hours in the early morning was found not to be completely effective in restoring Marine Corps volunteers from fatigue and sleepiness of 20 hours CW, thus making them ready to resume the second 2-hour CW with high quality performance. However, some task performances were found to be improved by napping. These findings suggest that napping can be used as an effective intervention technique for maintaining and even enhancing the cognitive performance during CW.



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